10/069962
JC19 Rec'd PCT/PTO 08 MAR 2002

SPECIFICATION

Title of the Invention

Even harmonic mixer

Field of the Invention

The present invention relates to an even harmonic mixer for use in transmitter-receivers intended for a radio communications system. More particularly, it relates to an even harmonic mixer that not only converts the frequency of a high frequency signal but also is suitable for a quadrature modulator and a quadrature demodulator for use with a modulation method, such as GMSK, QPSK, or QAM, which is frequently used in a digital radio communication system.

Background of the Invention

There is an even harmonic mixer which employs an antiparallel diode pair (APDP) as a means of mixing high-frequency signals. The principle of such an even harmonic mixer has been described in "Harmonic mixing with an antiparallel diode pair" by Marvin Cohn and et al., IEEE Transactions on Microwave theory and techniques, Vol. MTT-23, No. 8, pp. 667 to 673, August 1975. Fig. 1 is a schematic circuit diagram showing the structure of the prior art even harmonic mixer described in this reference. In the figure, reference numerals 1a and 1b denote first and second diodes, and reference numeral 2 denotes an APDP that consists of these diodes 1a and 1b. As shown in Fig. 1, in the APDP 2, the first and second diodes 1a and 1b are connected in parallel to each other so that they are opposite in polarity. Reference numeral 3 denotes a

demultiplexing circuit, reference numeral 4 denotes a high-pass filter (HPF) included in the demultiplexing circuit 3 and having an end connected to an RF terminal 7, reference numeral 5 is band-pass filter (BPF) included in the demultiplexing circuit 3 and having an end connected to another end of the HPF 4 and the APDP 2, and another end connected to an LO terminal 8, and reference numeral 6 denotes a low-pass filter (LPF) included in the demultiplexing circuit 3 and having an end connected to the HPF 4, the BPF 5, and the APDP 2, and another end connected to an IF terminal 9.

Next, a description will be made as to the operation of the prior art even harmonic mixer.

When the even harmonic mixer shown in Fig. 1 operates as a mixer for reception, a high frequency signal (RF signal) and a local oscillation wave (LO wave) are applied to the demultiplexing circuit 3 by way of the RF terminal 7 and the LO terminal 8, respectively. The RF signal applied to the RF terminal 7 is input to the APDP 2 by way of the HPF 4 of the demultiplexing circuit 3. At this time, leakage of the RF signal to the LO terminal 8 is prevented by the BPF 5. Furthermore, the LO wave applied to the LO terminal 8 is input to the APDP 2 by way of the BPF 5. At this time, leakage of the LO wave to the RF terminal 7 is prevented by the HPF 4. An intermediate-frequency signal (IF signal) is generated from the RF signal and the LO wave applied to the APDP 2. The generated IF signal is output to the IF terminal 9 which is an output signal terminal by way of the LPF 6. At this time, the RF signal and the LO wave are blocked by the LPF 6.

When the even harmonic mixer shown in Fig. 1 operates as a mixer for transmission, an IF signal and an LO wave are applied

to the demultiplexing circuit 3 by way of the IF terminal 9 and the LO terminal 8, respectively. The IF signal applied to the IF terminal 9 is input to the APDP 2 by way of the LPF 6. At this time, leakage of the IF signal to the RF terminal 7 is prevented by the HPF 4. Furthermore, leakage of the IF signal to the LO terminal 8 is prevented by the BPF 5. In addition, the LO wave applied to the LO terminal 8 is input to the APDP 2 by way of the BPF 5. At this time, leakage of the LO wave to the RF terminal 7 is prevented by the HPF 4. The APDP 2 generates an RF signal from the IF signal and the LO wave applied thereto. The generated RF signal is output to the RF terminal 7 which is an output signal terminal by way of the HPF 4.

Next, a frequency conversion operation will be explained.

Fig. 2 shows a relationship between a voltage across the APDP 2 and an electric current flowing through the APDP 2 which constitutes the even harmonic mixer. Since the first and second diodes 1a and 1b are connected in parallel to each other so that they are opposite in polarity, an electric current flows through the first diode 1a when the applied voltage is negative, whereas an electric current flows through the second diode 1b when the applied voltage is positive. By the way, the electric current which flows through each diode is generally given by the following equation.

$$I = Is*(\exp(qV/kT)-1) \qquad (1)$$

where Is is a saturation current, q is an electric charge, V is the applied voltage, k is Boltzmann's constant, and T is absolute temperature. When the electric current given by equation (1) shows a characteristic that it hardly flows until

the applied voltage V reaches a certain value Vt, and rapidly increases when the applied voltage V exceeds Vt. Therefore, the APDP 2 which consists of the first and second diodes 1a and 1b can be assumed to be an element which has a DC characteristic that the electric current flows only when the following condition: V>Vt or V<-Vt is established, as shown in Fig. 2. When applying an LO wave having an amplitude of Vp shown in Fig. 3 to the APDP 2 having such a DC characteristic, no electric current flows through either of the two diodes when the LO wave amplitude is in the range of -Vt from +Vt, and either one of the two diodes is turned on and an electric current therefore flows through the one of them when the LO wave amplitude exceeds +Vt or is less than -Vt, as shown in Fig. 4. As a result, the APDP 2 operates in such a manner that a low-frequency electric current whose phase changes in a half cycle thereof flows through the APDP 2, as shown in Fig. 5(a), and its conductance g given by the following equation increases in a half cycle of the electric current, as shown in Fig. 5(b).

$$g = dI/dV \qquad (2)$$

Fig. 5(b) means that the conductance g changes at a frequency two times that of the LO wave. Actually, when the waveform of the conductance is Fourier-analyzed, the term having a period twice that of the LO wave has a large coefficient. Thus, the even harmonic mixer, which employs the APDP 2, can output a mixture wave of the second harmonic of the LO wave and the input signal.

The prior art even harmonic mixer shown in Fig. 1 can operate with an LO wave of a frequency that is one-half of a desired frequency of an RF signal. Therefore, the even harmonic mixer

is applied to a transceiver for microwaves, especially, for millimeter waves, as disclosed in most public references including the above-mentioned reference. Since the even harmonic mixer can thus reduce the frequency of the LO wave to the half, transceivers that contains such an even harmonic mixer are expected to drop in price.

However, a problem with the even harmonic mixer which employs such an APDP is that the conversion gain, which is the ratio of the output signal to the input signal, changes greatly with a change in the LO wave electric power structurally. Fig. 6(a) is a graph showing an electric current which flows through the APDP 2 when the amplitude of an LO wave applied to the APDP is set to be equal to or less than its optimum value, Fig. 6(b) is a graph showing an electric current which flows through the APDP 2 when the amplitude of the LO wave applied to the APDP is set to be equal to its optimum value, and Fig. 6(c) is a graph showing an electric current which flows through the APDP 2 when the amplitude of the LO wave applied to the APDP is set to be equal to or greater than its optimum value. When the amplitude of the LO wave is set to be equal to or less than its optimum value, as shown in Fig. 6(a), an adequate conductance is not acquired and the conversion gain therefore decreases remarkably because the LO wave amplitude is insufficient. When the LO wave having an optimum amplitude is applied to the APDP 2, as shown in Fig. 6(b), an adequate conversion gain is acquired. When the LO wave having an amplitude equal to or greater than its optimum value is applied to the APDP 2, as shown in Fig. 6(c), the waveform of the electric current which flows through the APDP 2 becomes a sine wave having the same period as the LO wave. Therefore, in the Fourier series of the conductance, the term

with a period that is twice that of the LO wave has a small coefficient, and the level of a desired mixture wave which is a mixture of the second harmonic of the LO wave and the input signal decreases and the conversion gain therefore decreases. Fig. 7 shows such dependence of the conversion gain on the LO wave electric power. As can be seen from the figure, the conversion gain reaches its maximum value at a certain LO wave electric power and the conversion gain decreases before and behind the certain LO wave electric power.

Furthermore, since the saturation current Is in the above-mentioned equation (1) is a function of absolute temperature T and T is included in the exponential function of the equation (1), the DC characteristic of each diode has temperature dependence. Fig. 8 is a graph showing the temperature dependence of the DC characteristic of the APDP 2 equipped with the two diodes which have such temperature dependence and which are connected in parallel so that they are opposite in polarity. The threshold voltage Vt at which the electric current begins to flow through the APDP decreases with an increase in the temperature of each diode of the APDP. In other words, the threshold voltage becomes lower at a high temperature, whereas the threshold voltage becomes higher at a low temperature. Therefore, the dependence of the conversion gain on the LO wave electric power differs depending on the temperature of each diode of the APDP, as shown in Fig. 9. Therefore, even at the same electric power of the LO wave, the conversion gain differs according to the temperature of each diode of the APDP.

A problem with a prior art even harmonic mixer constructed as mentioned above is that the dependence of the conversion gain

on the LO wave electric power and the temperature dependence of the conversion gain must be considered when designing a communication apparatus and additional cost is therefore required. Another problem is that the level of the LO wave electric power supplied to the even harmonic mixer changes with variations in part performance, and variations in the characteristics of the even harmonic mixer and variations in part performance conspire to make the conversion gain of the prior art even harmonic mixer change greatly. A further problem is that at low temperatures since the conversion gain decreases the noise figure is deteriorated and the receiver sensitivity therefore decreases in receivers, and a desired output is not acquired in transmitters, whereas at high temperatures the conversion gain rises, the signal level rises, and distortion occurs at a stage located behind the even harmonic mixer.

The present invention is proposed to solve the above-mentioned problems, and it is therefore an object of the present invention to provide an even harmonic mixer capable of reducing the amount of change in the conversion gain resulting from a change in the amplitude of an LO wave applied thereto and a change in the temperature of each diode of an APDP included in the even harmonic mixer.

Disclosure of the Invention

An even harmonic mixer in accordance with an aspect of the present invention comprises an antiparallel diode pair means including a first series unit in which a first diode and a first resistor are connected in series and a second series unit in which a second diode and a second resistor are connected in series, the first and second series units being connected in parallel

so that the first and second diodes are opposite in polarity.

Accordingly, the aspect of the present invention offers an advantage of being able to reduce the amount of change in the conversion gain resulting from a change in the LO wave electric power and a change in the temperature of each diode of the antiparallel diode pair means because an electric current, which flows through each diode of the antiparallel diode pair means, can be kept nearly constant regardless of the amplitude of an LO wave applied to the antiparallel diode pair means and the temperature of each diode.

In the even harmonic mixer in accordance with another aspect of the present invention, the first series unit has a plurality of diodes in series which are connected in series to the first resistor, and the second series unit has a plurality of diodes in series which are connected in series to the second resistor.

Accordingly, the other aspect of the present invention offers an advantage of being able to provide an excellent distortion characteristic.

In the even harmonic mixer in accordance with a further aspect of the present invention, the first series unit has a first capacitor connected in parallel to the first resistor and the second series unit has a second capacitor connected in parallel to the second resistor.

Accordingly, the further aspect of the present invention offers an advantage of preventing a decrease in the level of an RF signal applied to the antiparallel diode pair means caused by the resistor connected in series to each diode because the RF signal passes through either the first capacitor or the second capacitor without passing through either the first resistor or

the second resistor.

In the even harmonic mixer in accordance with another aspect of the present invention, the first resistor is connected to a cathode of the first diode in the first series unit and the second resistor is connected to an anode of the second diode in the second series unit so that the first and second resistors are connected to each other at an end of the antiparallel diode pair means. The even harmonic mixer further comprises a first capacitor having an end connected to a node between the first resistor and the first diode and a second capacitor having an end connected to a node between the second resistor and the second diode, an IF signal is input and output by way of a node between the first and second resistors, other ends of the first and second capacitors are connected to each other, an LO wave is applied to a node between the other ends of the first and second capacitors, and an RF signal is input and output by way of the node between the other ends of the first and second capacitors.

Accordingly, the other aspect of the present invention offers an advantage of being able to reduce the amount of change in the conversion gain of the even harmonic mixer resulting from a change of the LO wave electric power and a change in the temperature of each diode of the antiparallel diode pair means, and to prevent a decrease in the level of an RF signal applied to the antiparallel diode pair means caused by the resistor connected in series to each diode.

In the even harmonic mixer in accordance with a further aspect of the present invention, the first resistor is connected to a cathode of the first diode in the first series unit and the second resistor is connected to an anode of the second diode in the second series unit so that the first and second resistors

are connected to each other at an end of the antiparallel diode pair means. The first series unit has a first capacitor connected in parallel to the first resistor and the second series unit has a second capacitor connected in parallel to the second resistor. The even harmonic mixer further comprises a third capacitor having an end connected to a node between the first resistor and the first diode and a fourth capacitor having an end connected to a node between the second resistor and the second diode, an IF signal is input and output by way of a node between the first and second resistors, other ends of the third and fourth capacitors are connected to each other, an LO wave is applied to a node between the other ends of the third and fourth capacitors, and an RF signal is input and output by way of the node between the other ends of the third and fourth capacitors.

Accordingly, the further aspect of the present invention offers an advantage of being able to reduce the amount of change in the conversion gain of the even harmonic mixer resulting from a change of the LO wave electric power and a change in the temperature of each diode of the antiparallel diode pair means, and to prevent a decrease in the level of an RF signal applied to the antiparallel diode pair means caused by the resistor connected in series to each diode.

In the even harmonic mixer in accordance with another aspect of the present invention, the first resistor is connected to a cathode of the first diode in the first series unit and the second resistor is connected to an anode of the second diode in the second series unit so that the first and second resistors are connected to each other at an end of the antiparallel diode pair means, and the first series unit comprises a first capacitor connected to an anode of the first diode and the second series

unit comprises a second capacitor connected to a cathode of the second diode. The even harmonic mixer further comprises a third resistor having an end connected to the anode of the first diode, a fourth resistor having an end connected to the cathode of the second diode and another end connected to another end of the third resistor, a third capacitor having an end connected to a node between the first resistor and the first diode, and a fourth capacitor having an end connected to a node between the second resistor and the second diode, an IF signal is input and output by way of a node between the first and second resistors, other ends of the third and fourth capacitors are connected to each other, an LO wave is applied to a node between the other ends of the third and fourth capacitors, and an RF signal is input and output by way of the node between the other ends of the third and fourth capacitors.

Accordingly, the other aspect of the present invention offers an advantage of being able to reduce the amount of change in the conversion gain of the even harmonic mixer resulting from a change of the LO wave electric power and a change in the temperature of each diode of the antiparallel diode pair means, and to prevent a decrease in the level of an RF signal applied to the antiparallel diode pair means caused by the resistor connected in series to each diode.

In the even harmonic mixer in accordance with a further aspect of the present invention, the first resistor is connected to a cathode of the first diode in the first series unit and the second resistor is connected to an anode of the second diode in the second series unit so that the first and second resistors are connected to each other at an end of the antiparallel diode pair means, and the first series unit comprises a third resistor

connected in series to an anode of the first diode and a first capacitor connected in parallel to the third resistor and the second series unit comprises a fourth resistor connected in series to a cathode of the second diode and a second capacitor connected in parallel to the fourth resistor. The even harmonic mixer further comprises a third capacitor having an end connected to a node between the first resistor and the first diode and a fourth capacitor having an end connected to a node between the second resistor and the second diode, an IF signal is input and output by way of a node between the first and second resistors, other ends of the third and fourth capacitors are connected to each other, an LO wave is applied to a node between the other ends of the third and fourth capacitors, and an RF signal is input and output by way of the node between the other ends of the third and fourth capacitors.

Accordingly, the further aspect of the present invention offers an advantage of being able to reduce the amount of change in the conversion gain of the even harmonic mixer resulting from a change of the LO wave electric power and a change in the temperature of each diode of the antiparallel diode pair means, and to prevent a decrease in the level of an RF signal applied to the antiparallel diode pair means caused by the resistor connected in series to each diode.

In the even harmonic mixer in accordance with another aspect of the present invention, the first resistor is connected to a cathode of the first diode in the first series unit and the second resistor is connected to an anode of the second diode in the second series unit so that the first and second resistors are connected to each other at an end of the antiparallel diode pair means, and the first series unit comprises a first capacitor

connected in parallel to the first resistor and a third capacitor connected in series to an anode of the first diode and the second series unit comprises a second capacitor connected in parallel to the second resistor and a fourth capacitor connected in series to a cathode of the second diode. The even harmonic mixer further comprises a third resistor having an end connected to the anode of the first diode and a fourth resistor having an end connected to the cathode of the second diode and another end connected to another end of the third resistor.

Accordingly, the other aspect of the present invention offers an advantage of being able to reduce the amount of change in the conversion gain of the even harmonic mixer resulting from a change of the LO wave electric power and a change in the temperature of each diode of the antiparallel diode pair means, and to prevent a decrease in the level of an RF signal applied to the antiparallel diode pair means caused by the resistor connected in series to each diode.

Brief Description of the Figures

Fig. 1 is a schematic circuit diagram showing the structure of a prior art even harmonic mixer;

Fig. 2 is a graph showing a DC characteristic of an APDP for use in the prior art even harmonic mixer;

Fig. 3 is a diagram showing the waveform of an LO wave applied to the APDP;

Fig. 4 is a graph showing a relationship between the waveform of the LO wave applied to the APDP and the waveform of a current which flows through the APDP;

Figs. 5(a) and 5(b) are graphs showing the waveform of a current which flows through each diode of the APDP and a

time-varying conductance of each diode;

Fig. 6(a), 6(b), and 6(c) are graphs showing the waveform of the current which flows through the APDP when setting the amplitude of the LO wave applied to the APDP to less than an optimum value, when setting it to the optimum value, and when setting it to greater than the optimum value;

Fig. 7 is a graph showing the dependence of a conversion gain of the prior art even harmonic mixer on the power of the LO wave;

Fig. 8 is a graph showing the temperature dependence of the DC characteristic of the APDP for use in the prior art even harmonic mixer;

Fig. 9 is a graph showing a change in the dependence of the conversion gain of the prior art even harmonic mixer on the LO wave power according to changes in temperature;

Fig. 10 is a schematic circuit diagram showing the structure of an even harmonic mixer according to a first embodiment of the present invention;

Fig. 11 is a graph showing a DC characteristic of an APDP for use in the even harmonic mixer according to the first embodiment of the present invention;

Fig. 12 is a graph showing the dependence of the conversion gain of the even harmonic mixer according to the first embodiment of the present invention on the power of an LO wave applied to the even harmonic mixer;

Fig. 13 is a graph showing the temperature dependence of the DC characteristic of the APDP for use in the even harmonic mixer according to the first embodiment of the present invention;

Fig. 14 is a graph showing a change in the dependence of the conversion gain of the even harmonic mixer according to

the first embodiment of the present invention on the LO wave power according to changes in temperature;

Fig. 15 is a schematic circuit diagram showing the structure of an even harmonic mixer according to a variant of the first embodiment of the present invention;

Fig. 16 is a schematic circuit diagram showing the structure of an even harmonic mixer according to another variant of the first embodiment of the present invention;

Fig. 17 is a schematic circuit diagram showing the structure of another example of the APDP for use in the even harmonic mixer according to the first embodiment of the present invention;

Fig. 18 is a schematic circuit diagram showing the structure of another example of the APDP for use in the even harmonic mixer according to the first embodiment of the present invention;

Fig. 19 is a schematic circuit diagram showing the structure of another example of the APDP for use in the even harmonic mixer according to the first embodiment of the present invention;

Fig. 20 is a schematic circuit diagram showing the structure of an even harmonic mixer according to a second embodiment of the present invention;

Fig. 21 is a schematic circuit diagram showing the structure of an even harmonic mixer according to a third embodiment of the present invention;

Fig. 22 is a diagram showing a flow of an RF signal in an APDP for use in the even harmonic mixer according to the third embodiment of the present invention;

Fig. 23 is a schematic circuit diagram showing the

structure of an even harmonic mixer according to a variant of the third embodiment of the present invention;

Fig. 24 is a schematic circuit diagram showing the structure of an even harmonic mixer according to a fourth embodiment of the present invention;

Fig. 25 is a diagram showing a flow of an RF signal in an APDP for use in the even harmonic mixer according to the fourth embodiment of the present invention;

Fig. 26 is a schematic circuit diagram showing the structure of an even harmonic mixer according to a variant of the fourth embodiment of the present invention;

Fig. 27 is a schematic circuit diagram showing the structure of an even harmonic mixer according to a fifth embodiment of the present invention;

Fig. 28 is a schematic circuit diagram showing the structure of an even harmonic mixer according to a variant of the fifth embodiment of the present invention;

Fig. 29 is a schematic circuit diagram showing the structure of an even harmonic mixer according to a sixth embodiment of the present invention;

Fig. 30 is a schematic circuit diagram showing the structure of an even harmonic mixer according to a variant of the sixth embodiment of the present invention;

Fig. 31 is a schematic circuit diagram showing the structure of an even harmonic mixer according to a seventh embodiment of the present invention;

Fig. 32 is a schematic circuit diagram showing the structure of an even harmonic mixer according to a variant of the seventh embodiment of the present invention;

Fig. 33 is a schematic circuit diagram showing the

structure of an even harmonic mixer according to an eighth embodiment of the present invention; and

Fig. 34 is a schematic circuit diagram showing the structure of an even harmonic mixer according to a variant of the eighth embodiment of the present invention.

Preferred Embodiments of the Invention

Hereafter, to explain the present invention more in detail, the preferred embodiments which embody the present invention will be explained with reference to the accompanied drawings.

Embodiment 1.

Fig. 10 is a schematic circuit diagram showing the structure of an even harmonic mixer according to a first embodiment of the present invention. In the figure, reference numerals 1a and 1b denote first and second diodes, respectively, reference numerals 10a and 10b denote first and second resistors, respectively, and reference numeral 11 denotes an antiparallel diode pair unit (antiparallel diode pair means) that consists of the first and second diodes 1a and 1b and the first and second resistors 10a and 10b. In the following, the antiparallel diode pair unit is abbreviated as APDP. As shown in Fig. 10, in the APDP 11, the first and second diodes 1a and 1b are connected in parallel so that they are opposite in polarity and the corresponding resistor is connected in series to the cathode of each of those diodes. In other words, the APDP 11 consists of a first series unit in which the first diode 1a and the first resistor 10a are connected in series and a second series unit in which the second diode 1b and the second resistor 10b are connected in series, the first and second series units being connected in parallel so that the first and second diodes 1a

and 1b are opposite in polarity.

Furthermore, reference numeral 3 denotes a demultiplexing circuit, reference numeral 4 denotes a HPF included in the demultiplexing circuit 3 and having an end connected to an RF terminal 7, reference numeral 5 denotes a BPF included in the demultiplexing circuit 3 and having an end connected to both another end of the HPF 4 and an end of the APDP 11, and another end connected to an LO terminal 8, reference numeral 6 denotes a LPF included in the demultiplexing circuit 3 and having an end connected to the other end of the HPF 4, the end of the BPF 5, and the end of the APDP 11, and another end connected to an IF terminal 9. The other end of the APDP 11 is connected to a ground potential.

Next, a description will be made as to the operation of the even harmonic mixer according to the first embodiment.

Fig. 11 is a graph showing a relationship between a voltage across the terminals of the APDP 11 and an electric current which flows through the APDP 11 at room temperatures. In the following, the operation of the even harmonic mixer according to the first embodiment will be explained with reference to Fig. 11. Like a prior art APDP, the APDP 11 shows a DC characteristic that the electric current hardly flows until the voltage V applied across its terminals reaches a certain value Vt, and increases rapidly when V exceeds Vt. Therefore, it can be assumed that the APDP 11 according to the first embodiment to be an element having a DC characteristic that the electric current flows only when the following condition: V>Vt or V<-Vt is established, as shown in Fig. 11. However, a rate of increase of the electric current which flows through the APDP 11 according to an increase in the terminal voltage of the APDP 11 is smaller than that of

the prior art APDP 2. The change in the electric current which flows through the APDP 11 is an extremely small even if the terminal voltage changes somewhat. In other words, since the electric current, which flows through each diode of the APDP, can be kept nearly constant regardless of the amplitude of an LO wave applied to the APDP and the temperature of each diode, variations in the conductance can be reduced. Therefore, when an LO wave is applied to the APDP 11 having such a DC characteristic, the amount of change in the conversion gain resulting from a change in the LO wave electric power and a change in the temperature of each diode of the APDP can be reduced.

Fig. 12 is a graph showing a relationship between the electric power of an LO wave applied to the APDP 11 in which the first and second resistors 10a and 10b are connected in series to the first and second diodes 1a and 1b, respectively, as shown in Fig. 10, and the conversion gain. While the conversion gain increases rapidly when the electric power of the LO wave applied to the APDP 11 exceeds a threshold value, as in the case of the DC characteristic shown in Fig. 11, the conversion gain reaches its maximum value when the LO wave electric power reaches a predetermined value Po, and the conversion gain then decreases slowly as the LO wave electric power exceeds Po and increases. Thus, the APDP 11 according to the first embodiment has a dependence of the conversion gain on the LO wave electric power that the amount of change in the conversion gain resulting from a change in the LO wave electric power is small when the LO wave electric power exceeds the predetermined value Po. Therefore, the amount of change in the conversion gain resulting from the change in the LO wave electric power can be reduced.

In addition to the above-mentioned advantage of providing

a small dependence of the conversion gain on the LO wave power when the LO wave electric power exceeds the predetermined value Po, the present invention offers another advantage of being able to reduce the amount of change in the conversion gain caused by a change in the DC characteristic resulting from a change in the temperature of each diode of the APDP. Fig. 13 shows the DC characteristic of the APDP 11 at a high temperature and a low temperature of each diode as well as the DC characteristic of the APDP 11 at a normal temperature of each diode. As previously mentioned, a rate of increase of the electric current which flows through the APDP 11 according to an increase in the terminal voltage of the APDP 11 is smaller than that of the prior art APDP 2, and the change in the electric current which flows through the APDP 11 is extremely small even if the terminal voltage changes somewhat. As a result, the electric current, which flows through the APDP 11, hardly changes if the same terminal voltage is applied to the APDP 11 even though the temperature of each diode of the APDP changes. Fig. 14 is a graph showing a change in the dependence of the conversion gain of the APDP 11 on the LO wave electric power resulting from a change in the temperature of each diode. As shown in the figure, while the conversion gain of the APDP 11 changes somewhat with a change in the temperature of each diode, the change in the conversion gain with temperature is very small when the LO wave electric power having the predetermined value Po or more is applied to the APDP.

As previously mentioned, in accordance with the first embodiment, the even harmonic mixer makes it possible to reduce the amount of change of the conversion gain resulting from a change in the electric power of an LO wave applied to the even harmonic mixer and a change in the temperature of each diode

of the APDP.

Numerous variants may be made in the first embodiment mentioned above as follows.

Fig. 15 is a schematic circuit diagram showing the structure of an even harmonic mixer according to a variant of the first embodiment. The even harmonic mixer according to this variant is a stub demultiplexing mixer. In the figure, the same reference numerals as shown in Fig. 10 denote the same components as those of the even harmonic mixer according to the above-mentioned first embodiment or like components. Furthermore, reference numeral 12 denotes a line with an open end, having an electrical length equal to one quarter-wavelength of an LO wave applied to the even harmonic mixer, and reference numeral 13 denotes a line with a short-circuited end, having an electrical length equal to one quarter-wavelength of the LO wave.

The stub demultiplexing mixer shown in Fig. 15 is used when the frequency of an IF signal applied to the even harmonic mixer is lower than the frequency of the LO wave. At the frequency of the LO wave, the line 13 with a short-circuited end is assumed to be open when viewed from a node A between the line 13 and the APDP 11 and the line 12 with an open end is assumed to be short-circuited when viewed from a node B between the line 12 and the APDP 11. Therefore, the LO wave applied to the LO terminal 8 flows into the line 12 with an open end by way of the APDP 11. Furthermore, since the frequency of the IF signal is lower than the frequency of the LO wave, the frequency of an RF signal applied to the even harmonic mixer becomes about twice the frequency of the LO wave. Therefore, at the frequency of the RF signal, the line 13 with a short-circuited end is assumed

to be short-circuited when viewed from the node A between the line 13 and the APDP 11 and the line 12 with an open end is assumed to be open when viewed from the node B between the line 12 and the APDP 11. Therefore, the RF signal applied to the RF terminal 7 flows into the line 13 with a short-circuited end by way of the APDP 11.

Even in this variant, since the DC characteristic of the APDP 11 which consists of the first and second resistors 10a and 10b and the first and second diodes 1a and 1b connected in series to those resistors, respectively, does not greatly depend on a change in the LO wave electric power and a change in the temperature of each diode, it is possible to control the change in the conversion gain resulting from the change in the LO wave electric power and the change in the temperature of each diode.

Although it is assumed that the IF signal is an unbalanced signal in the above-mentioned explanation, the first embodiment is not limited to the case. Alternatively, the first embodiment can also be applied to a case where the IF signal is a balanced signal. Fig. 16 is a schematic circuit diagram showing the structure of an even harmonic mixer for mixing an IF signal which is a balanced signal according to another variant of the first embodiment. In the figure, reference numeral 40 denotes a HPF disposed between the APDP 11 and a ground potential, for allowing only an RF signal and an LO wave to pass therethrough, and reference numeral 6b denotes a LPF having an end connected to a node between the HPF 40 and the APDP 11, and another end connected to an inverted IF terminal 9b via which the inversion of an IF signal is input and output. The HPF 40 may be a simple circuit which consists of only a capacitor. And, the IF signal which is a balanced signal and the inversion of the IF signal are input and output

by way of the IF terminal 9a and the inverted IF terminal 9b, respectively. Even in the even harmonic mixer constructed as above, since the DC characteristic of the APDP 11 does not greatly depend on a change in the LO wave electric power and a change in the temperature of each diode of the APDP, it is possible to control the change in the conversion gain resulting from the change in the LO wave electric power and the change in the temperature of each diode.

Fig. 17 is a schematic circuit diagram showing the structure of an APDP 11 according to another variant of the first embodiment. In this variant, the first and second resistors 10a and 10b are connected to the anodes of the first and second diodes 1a and 1b which constitute the APDP 11, respectively. When the APDP 11 according to this variant is applied to an even harmonic mixer, the same advantage is provided. In other words, it is possible to control the change in the conversion gain resulting from the change in the LO wave electric power and the change in the temperature of each diode of the APDP.

Fig. 18 is a schematic circuit diagram showing the structure of an APDP 11 according to another variant of the first embodiment. In this variant, the first resistor 10a is connected to the cathode of the first diode 1a and the second resistor 10b is connected to the anode of the second diode 1b. When the APDP 11 according to this variant is applied to an even harmonic mixer, the same advantage is provided. In other words, it is possible to control the change in the conversion gain resulting from the change in the LO wave electric power and the change in the temperature of each diode.

Although the number of resistors connected in series to each diode included in the APDP 11 is one in the above-mentioned

embodiment and variants, in accordance with the present invention the number of resistors is not limited to one and a plurality of resistors can be connected to each diode of the APDP. Fig. 19 is a schematic circuit diagram showing the structure of an APDP 11 according to such a variant. In this variant, the number of resistors connected in series to each diode which constitutes the APDP 11 is two, and two resistors are connected to both the anode and cathode of each diode, respectively. When the APDP 11 according to this variant is applied to an even harmonic mixer, the same advantage is provided. In other words, it is possible to control the change in the conversion gain resulting from the change in the LO wave electric power and the change in the temperature of each diode of the APDP.

Embodiment 2.

Fig. 20 is a schematic circuit diagram showing the structure of an even harmonic mixer according to a second embodiment of the present invention. In the figure, the same reference numerals as shown in Fig. 10 denote the same components as those of the even harmonic mixer according to the above-mentioned first embodiment or like components, and the explanation of those components will be omitted hereafter. Furthermore, in Fig. 20, reference numeral 1c denotes a third diode connected in series to a first diode 1a, and reference numeral 1d denotes a fourth diode connected in series to a second diode 1b. Thus, in an APDP 11 according to the second embodiment, a first series unit which consists of the two diodes 1a and 1c connected in series (cascaded) and a first resistor 10a connected in series to those diodes 1a and 1c, and a second series unit which consists of the two remaining diodes 1b and 1d connected

in series and a second resistor 10b connected in series to those diodes 1b and 1d are connected in parallel so that the first set of diodes 1a and 1c and the second set of diodes 1b and 1d are opposite in polarity.

Next, a description will be made as to the operation of the even harmonic mixer according to the second embodiment.

The APDP 11 incorporated into the even harmonic mixer according to the second embodiment operates basically in the same way that the APDP 11 according to the above-mentioned first embodiment does. Therefore, only a characterized operation of the even harmonic mixer according to the second embodiment will be explained in the following.

Since two diodes are cascaded in each series unit of the APDP 11, the terminal voltage applied to each diode stage included in each series unit is reduced to half that across each diode included in each series unit of the APDP of the even harmonic mixer of the first embodiment. In general, distortion to be created in a diode grows nonlinearly as the terminal voltage applied to the diode increases. Therefore, it is possible to reduce the amount of distortion to be created when the level of an input signal is increased as compared with the case where only one diode is provided in each series unit. In other words, an excellent distortion characteristic is acquired.

Furthermore, needless to say that even in the even harmonic mixer which employs the APDP 11 constructed as above, since the APDP 11 shows a DC characteristic that does not greatly depend on a change in the LO wave electric power and a change in the temperature of each diode of the APDP, like the APDP of the above-mentioned first embodiment, it is possible to reduce the amount of change in the conversion gain resulting from the change

in the LO wave electric power and the change in the temperature of each diode of the APDP.

The number of diodes cascaded in each series unit which constitutes the APDP 11 is not limited to two, and the APDP 11 can alternatively be comprised of two series units in each of which three or more diodes are cascaded. This variant makes it possible to further reduce the amount of distortion to be created when the level of an input signal is increased.

Embodiment 3.

Fig. 21 is a schematic circuit diagram showing the structure of an even harmonic mixer according to a third embodiment of the present invention. In the figure, the same reference numerals as shown in Fig. 10 denote the same components as those of the even harmonic mixer according to the above-mentioned first embodiment or like components, and the explanation of those components will be omitted hereafter. Furthermore, in Fig. 21, reference numeral 14a denotes a first capacitor connected in parallel to a first resistor 10a connected in series to a first diode 1a, and reference numeral 14b denotes a second capacitor connected in parallel to a second resistor 10b connected in series to a second diode 1b. Thus, in an APDP 11 according to the third embodiment, a first series unit which consists of the first diode 1a and the first resistor 10a connected in series, and the first capacitor 14a connected in parallel to the first resistor 10a, and a second series unit which consists of the second diode 1b and the second resistor 10b connected in series, and the second capacitor 14b connected in parallel to the second resistor 10b are connected in parallel so that the first and second diodes 1a and 1b are opposite in polarity.

Next, the operation of the even harmonic mixer according to the third embodiment will be explained.

The description will be made assuming that the even harmonic mixer is the one intended for reception, and an RF signal and an LO wave are applied to an RF terminal 7 and an LO terminal LO 8, respectively, and an IF signal is extracted from an IF terminal 9. The APDP 11 incorporated into the even harmonic mixer according to the third embodiment operates basically in the same way that the APDP 11 according to the above-mentioned first embodiment does. Therefore, only a characterized operation of the even harmonic mixer of the third embodiment will be explained in the following.

Fig. 22 is a diagram for explaining a flow of an RF signal in the APDP 11 according to the third embodiment. Not only an LO wave but also an RF signal should be applied to the APDP 11 when the even harmonic mixer operates as a mixer for reception. When the even harmonic mixer does not include the first and second capacitors 14a and 14b (that is, in the case of the above-mentioned first embodiment shown in Fig. 10), a voltage drop is caused in either the first resistor 10a or the second resistor 10b connected in series to each diode when an RF signal is applied to the APDP 11, and this results in a decrease in the voltage of the RF signal applied to each diode. As a result, the conversion gain is reduced.

In contrast, in the APDP 11 according to the third embodiment shown in Fig. 22, the RF signal applied to the APDP passes through the second capacitor 14b other than the second resistor 10b in positive cycles of the RF signal. On the other hand, the RF signal passes the first capacitor 14a other than the first resistor 10a in negative cycles of the RF signal. As

a result, since no voltage drop is caused because of the first resistor 10a or the second resistor 10b, it is possible to reduce the amount of change in the conversion gain resulting from a change in the LO wave electric power of the even harmonic mixer and a change in the temperature of each diode of the APDP without causing a decrease in the conversion gain.

The even harmonic mixer according to the third embodiment can be used as a mixer for transmission in which an IF signal is input and an RF signal and an LO wave are output. In this case, the same advantage is provided.

Numerous variants may be made in the third embodiment mentioned above as follows.

Although it is assumed that the IF signal is an unbalanced signal in the above-mentioned explanation, the third embodiment is not limited to the case. Alternatively, the third embodiment can also be applied to a case where the IF signal is a balanced signal. Fig. 23 is a schematic circuit diagram showing the structure of an even harmonic mixer for mixing an IF signal which is a balanced signal according to a variant of the third embodiment. In the figure, reference numeral 40 denotes a HPF disposed between the APDP 11 and a ground potential, for allowing only an RF signal and an LO wave to pass therethrough, and reference numeral 6b denotes a LPF having an end connected to a node between the HPF 40 and the APDP 11, and another end connected to an inverted IF terminal 9b. The HPF 40 may be a simple circuit which consists of only a capacitor. And, the IF signal which is a balanced signal and the inversion of the IF signal are input and output by way of the IF terminal 9a and the inverted IF terminal 9b. Even in the even harmonic mixer constructed as above, since the DC characteristic of the APDP 11 does not greatly depend on a

change in the LO wave electric power and a change in the temperature of each diode of the APDP, it is possible to reduce the amount of change in the conversion gain resulting from the change in the LO wave electric power and the change in the temperature of each diode.

In another variant of the third embodiment, both first and second resistors 10a and 10b and first and second capacitors 14a and 14b are connected to anodes of the first and second diodes 1a and 1b which constitute the APDP 11, respectively. When the APDP 11 according to this variant is applied to an even harmonic mixer, the same advantage is provided. In other words, it is possible to reduce the amount of change in the conversion gain resulting from a change in the LO wave electric power and a change in the temperature of each diode of the APDP.

Furthermore, in another variant of the third embodiment, a first resistor 10a and a first capacitor 14a are connected to an anode of the first diode 1a, and a second resistor 10b and a second capacitor 14b are connected to a cathode of the second diode 1b. When the APDP 11 according to this variant is applied to an even harmonic mixer, the same advantage is provided. In other words, it is possible to reduce the amount of change in the conversion gain resulting from a change in the LO wave electric power and a change in the temperature of each diode of the APDP.

Furthermore, in another variant of the third embodiment, a parallel circuit in which a resistor and a capacitor are connected in parallel is connected to each of the anode and cathode of the first diode 1a, and a parallel circuit in which a resistor and a capacitor are connected in parallel is connected to each of the anode and cathode of the second diode 1b. When the APDP

11 according to this variant is applied to an even harmonic mixer, the same advantage is provided. In other words, it is possible to reduce the amount of change in the conversion gain resulting from a change in the LO wave electric power and a change in the temperature of each diode of the APDP.

Although the number of diodes included in each series unit which constitutes the APDP 11 is one in the above-mentioned third embodiment and variants, the number of diodes is not limited to one and two or more diodes can be cascaded in each series unit of the APDP 11. This variant makes it possible to further reduce the amount of distortion to be created when the level of an input signal is increased, as previously mentioned in Embodiment 2.

Embodiment 4.

Fig. 24 is a schematic circuit diagram showing the structure of an even harmonic mixer according to a fourth embodiment of the present invention. In the figure, the same reference numerals as shown in Fig. 10 denote the same components as those of the even harmonic mixer according to the above-mentioned first embodiment or like components, and the explanation of those components will be omitted hereafter. Furthermore, in Fig. 24, reference numeral 15a denotes a first capacitor having an end connected to a node between a cathode of a first diode 1a and a first resistor 10a, and reference numeral 15b denotes a second capacitor having an end connected to a node between an anode of a second diode 1b and a second resistor 10b. In an APDP 11 according to the fourth embodiment, the first resistor 10a is connected to the cathode of the first diode 1a in a first series unit and the second resistor 10b is connected

to the anode of the second diode 1b in a second series unit so that the first and second resistors 10a and 10b are connected to each other at an end of the APDP 11.

The other ends of the first and second capacitors 15a and 15b are connected to each other, and furthermore, a node between them is connected to an RF terminal 7 by way of a HPF 4 and is also connected to an LO terminal 8 by way of a BPF 5. Furthermore, a node between the first and second resistors 10a and 10b is connected to an IF terminal 9. Each of the first and second capacitors 15a and 15b has a capacitance that is set to a value to allow an RF signal and an LO wave to pass therethrough and to block an IF signal.

Next, the operation of the even harmonic mixer according to the fourth embodiment will be explained.

The description will be made assuming that the even harmonic mixer is the one intended for reception, and an RF signal and an LO wave are applied to the RF terminal 7 and the LO terminal 8, respectively, and an IF signal is extracted from the IF terminal 9. Fig. 25 shows a flow of the RF signal in the APDP 11 according to the fourth embodiment. The RF signal applied to the APDP 11 passes through the first capacitor 15a or the second capacitor 15b, and then enters the first diode 1a or the second diode 1b. Therefore, any voltage drop in the RF signal according to the resistor connected in series to each diode is not caused, as in the case of the third embodiment. On the other hand, since a direct current is blocked by the first and second capacitors 15a and 15b, a parallel circuit constructed of the first series unit which consists of the first diode 1a and the first resistor 10a and the second series unit which consists of the second diode 1b and the second resistor 10b, operates like the APDP according

to the above-mentioned first embodiment. Therefore, even in the even harmonic mixer which employs the APDP 11 constructed as above, since the DC characteristic of the APDP 11 does not greatly depend on a change in the LO wave electric power and a change in the temperature of each diode of the APDP, it is possible to reduce the amount of change in the conversion gain resulting from the change in the LO wave electric power and the change in the temperature of each diode of the APDP.

In addition, since the IF signal generated by the first diode 1a or the second diode 1b is blocked by the first and second capacitors 15a and 15b, the IF signal is output by way of the IF terminal 9 connected to the node between the first and second resistors 10a and 10b. At this time, the RF signal is blocked by the first and second resistors 10a and 10b and does not appear at the IF terminal 9 because the impedance of each of the first and second capacitors 15a and 15b is smaller than the resistance of each of the first and second resistors 10a and 10b. Therefore, a LPF for allowing only an IF signal to pass therethrough, which is needed in the above-mentioned embodiments, becomes unnecessary.

The even harmonic mixer according to the fourth embodiment is available as a mixer for transmission which inputs an IF signal and outputs an RF signal and an LO wave, and offers the same advantages.

Numerous variants may be made in the fourth embodiment mentioned above as follows.

Although it is assumed that the IF signal is an unbalanced signal in the above-mentioned explanation, the fourth embodiment is not limited to the case. Alternatively, the fourth embodiment can also be applied to a case where the IF signal is a balanced

signal. Fig. 26 is a schematic circuit diagram showing the structure of an even harmonic mixer for mixing an IF signal which is a balanced signal according to a variant of the fourth embodiment. In the figure, reference numeral 40 denotes a HPF disposed between the APDP 11 and a ground potential, for allowing only an RF signal and an LO wave to pass therethrough, and reference numeral 6b denotes a LPF having an end connected to a node between the HPF 40 and the APDP 11, and another end connected to an inverted IF terminal 9b. The HPF 40 may be a simple circuit which consists of only a capacitor. And, the IF signal which is a balanced signal and the inversion of the IF signal are input and output by way of the IF terminal 9a and the inverted IF terminal 9b. Since the even harmonic mixer according to this variant operates like the even harmonic mixer of Fig.16 and the APDP 11 shows a DC characteristic that does not greatly depend on a change in the LO wave electric power and a change in the temperature of each diode of the APDP, like that as shown in Fig. 24, it is possible to reduce the amount of change in the conversion gain resulting from the change in the LO wave electric power and the change in the temperature of each diode of the APDP.

Although the number of diodes included in each series unit which constitutes the APDP 11 is one in the above-mentioned fourth embodiment and variants, the number of diodes is not limited to one and two or more diodes can be cascaded in each series unit of the APDP. This variant makes it possible to further reduce the amount of distortion to be created when the level of an input signal is increased.

Embodiment 5.

Fig. 27 is a schematic circuit diagram showing the

structure of an even harmonic mixer according to a fifth embodiment of the present invention. In the figure, the same reference numerals as shown in Fig. 21 denote the same components as those of the even harmonic mixer according to the above-mentioned third embodiment or like components, and the explanation of those components will be omitted hereafter. In an APDP 11 according to the fifth embodiment, a first resistor 10a is connected to a cathode of a first diode 1a in a first series unit of the APDP and a second resistor 10b is connected to an anode of a second diode 1b in a second series unit of the APDP so that the first and second resistors 10a and 10b are connected to each other at an end of the APDP. Furthermore, a first capacitor 14a is connected in parallel to the first resistor 10a and a second capacitor 14b is connected in parallel to the first resistor 10b. A node between the first and second resistors 10a and 10b is connected to an IF terminal 9.

Furthermore, in Fig. 27, reference numeral 15a denotes a third capacitor having an end connected to a node between the cathode of the first diode 1a and the first resistor 10a, and reference numeral 15b denotes a fourth capacitor having an end connected to a node between the anode of the second diode 1b and the second resistor 10b. The other ends of the third and fourth capacitors 15a and 15b are connected to each other, and a node between them is connected to an RF terminal 7 by way of a HPF 4 and is also connected to an LO terminal 8 by way of a BPF 5. Each of the first and second capacitors 14a and 14b has a capacitance that is set to allow an IF signal to pass therethrough, and each of the third and fourth capacitors 15a and 15b has a capacitance that is set to allow an RF signal and an LO wave to pass therethrough, and to block the IF signal.

Next, the operation of the even harmonic mixer according to the fifth embodiment will be explained.

The description will be made assuming that the even harmonic mixer is the one intended for reception, and an RF signal and an LO wave are applied to the RF terminal 7 and the LO terminal 8, respectively, and an IF signal is extracted from the IF terminal 9. In the above-mentioned fourth embodiment shown in Fig. 24, the IF signal passes through the first resistor 10a or the second resistor 10b and is output to the IF terminal 9. Therefore, the IF signal may be attenuated because of the first resistor 10a or the second resistor 10b. In contrast, in the fifth embodiment, since the first and second capacitors 14a and 14b are connected in parallel to the first and second resistors 10a and 10b, respectively, the IF signal is output to, by way of the IF terminal 9, outside the mixer without being attenuated because of the first and second resistors 10a and 10b by setting the capacitance of each of the first and second capacitors 14a and 14b to a value to allow the IF signal to pass therethrough.

Thus, neither the first capacitor 14a nor the second capacitor 14b has an influence on the electric currents which flow through the first diode 1a and the second diode 1b included in the two series units of the APDP 11, respectively, and therefore the electric currents which flow through the first diode 1a and the second diode 1b can be kept constant with the first resistor 10a or the second resistor 10b. Thus, even in the even harmonic mixer which employs the APDP 11 constructed as above, since the DC characteristic of the APDP 11 does not greatly depend on a change in the LO wave electric power and a change in the temperature of each diode of the APDP, it is possible to reduce the amount of change in the conversion gain resulting from the change in

the LO wave electric power and the change in the temperature of each diode of the APDP.

The even harmonic mixer according to the fifth embodiment is available as a mixer for transmission which inputs an IF signal and outputs both an RF signal and an LO wave, and offers the same advantages.

Numerous variants may be made in the fifth embodiment mentioned above as follows.

Although it is assumed that the IF signal is an unbalanced signal in the above-mentioned explanation, the fifth embodiment is not limited to the case. Alternatively, the fifth embodiment can also be applied to a case where the IF signal is a balanced signal. Fig. 28 is a schematic circuit diagram showing the structure of an even harmonic mixer for mixing an IF signal which is a balanced signal according to a variant of the fifth embodiment. In the figure, reference numeral 40 denotes a HPF disposed between the APDP 11 and a ground potential, for allowing only an RF signal and an LO wave to pass therethrough, and reference numeral 6b denotes a LPF having an end connected to a node between the HPF 40 and the APDP 11, and another end connected to an inverted IF terminal 9b. The HPF 40 may be a simple circuit which consists of only a capacitor. And, the IF signal which is a balanced signal and the inversion of the IF signal are input and output by way of the IF terminal 9a and the inverted IF terminal 9b. Since the even harmonic mixer according to this variant operates like the even harmonic mixer of Fig. 16 and the APDP 11 shows a DC characteristic that does not greatly depend on a change in the LO wave electric power and a change in the temperature of each diode of the APDP, like that as shown in Fig. 27, it is possible to reduce the amount of change in the conversion

gain resulting from the change in the LO wave electric power and the change in the temperature of each diode of the APDP.

Although the number of diodes included in each series unit which constitutes the APDP 11 is one in the above-mentioned fifth embodiment and variants, the number of diodes is not limited to one and two or more diodes can be cascaded in each series unit of the APDP. This variant makes it possible to further reduce the amount of distortion to be created when the level of an input signal is increased, as mentioned in Embodiment 2.

Embodiment 6.

Fig. 29 is a schematic circuit diagram showing the structure of an even harmonic mixer according to a sixth embodiment of the present invention. In the figure, the same reference numerals as shown in Fig. 10 denote the same components as those of the even harmonic mixer according to the above-mentioned first embodiment or like components, and the explanation of those components will be omitted hereafter. In an APDP 11 according to the sixth embodiment, a first resistor 10a is connected to a cathode of a first diode 1a in a first series unit of the APDP and a second resistor 10b is connected to an anode of a second diode 1b in a second series unit of the APDP so that the first and second resistors 10a and 10b are connected to each other at an end of the APDP.

Furthermore, in Fig. 29, reference numeral 17a denotes a first capacitor having an end connected in series to an anode of the first diode 1a, reference numeral 17b denotes a second capacitor having an end connected in series to a cathode of the second diode 1b, reference numeral 18a denotes a third capacitor having an end connected to a node between the cathode of the

first diode 1a and the first resistor 10a, reference numeral 18b denotes a fourth capacitor having an end connected to a node between the anode of the second diode 1b and the second resistor 10b, reference numeral 19a denotes a third resistor having an end connected to a node between the anode of the first diode 1a and the first capacitor 17a, and reference numeral 19b denotes a fourth resistor having an end connected to a node between the cathode of the second diode 1b and the second capacitor 17b. The other ends of the first and second capacitors 17a and 17b are connected to each other and a node between them is connected to a ground potential. The first and second resistors 10a and 10b are connected to each other and a node between them is connected to an IF terminal 9a. The third and fourth resistors 19a and 19b are connected to each other and a node between them is connected to an inverted IF terminal 9b. The other ends of the third and fourth capacitors 18a and 18b are connected to other, and a node between them is connected to an RF terminal 7 by way of a HPF 4 and is also connected to an LO terminal 8 by way of a BPF 5. Each of the first and second capacitors 17a and 17b and the third and fourth capacitors 18a and 18b has a capacitance set to a value which allows an RF signal and an LO wave to pass therethrough and blocks an IF signal.

Next, the operation of the even harmonic mixer according to the sixth embodiment will be explained.

The description will be made assuming that the even harmonic mixer is the one intended for reception in which an RF signal and an LO wave are applied to the RF terminal 7 and the LO terminal 8, respectively, and an IF signal and the inversion of the IF signal are extracted from the IF terminal 9a and the inverted IF terminal 9b, respectively.

The RF signal applied to the RF terminal 7 is input to the APDP 11 by way of the HPF 4. The input RF signal is then furnished to either the first diode 1a or the second diode 1b by way of the third capacitor 18a or the fourth capacitor 18b, and further reaches the ground potential by way of either the first capacitor 17a or the second capacitor 17b. Therefore, any voltage drop in the RF signal is not caused because of the first through fourth resistors 10a, 10b, 19a, and 19b. On the other hand, since a direct current is blocked by the first through fourth capacitors 17a, 17b, 18a, and 18b, a parallel circuit, which consists of a series unit (which differs from the first series unit) in which the first diode 1a and the first and third resistors 10a and 19a are connected to each other and another series unit (which differs from the second series unit) in which the second diode 1b and the second and fourth resistors 10b and 19b are connected to each other, operates like the APDP according to the above-mentioned first embodiment. Therefore, even in the even harmonic mixer which employs the APDP 11 constructed as above, since the DC characteristic of the APDP 11 does not greatly depend on a change in the LO wave electric power and a change in the temperature of each diode of the APDP, it is possible to reduce the amount of change in the conversion gain resulting from the change in the LO wave electric power and the change in the temperature of each diode of the APDP.

Furthermore, because the IF signal generated by either the first diode 1a or the second diode 1b is blocked by the first and second capacitors 17a and 17b and the third and fourth capacitors 18a and 18b, the IF signal and the inversion of the IF signal are output from a node between the first and second resistors 10a and 10b and a node between the third and fourth

resistors 19a and 19b, respectively. At this time, the RF signal is blocked by the first through fourth resistors 10a, 10b, 19a, and 19b and does not appear at the IF terminal 9a and the inverted IF terminal 9b because each of the first through fourth capacitors 17a, 17b, 18a, and 18b has an impedance smaller than the resistance of each of the first through fourth resistors 10a, 10b, 19a, and 19b. Therefore, the even harmonic mixer of the sixth embodiment makes it possible to output the IF signal as a balanced signal even if there is no low-pass filter that allows only IF signals to pass therethrough, though such a low-pass filter is needed in the first through third embodiments mentioned above.

The even harmonic mixer according to the sixth embodiment is available as a mixer for transmission which inputs an IF signal and outputs both an RF signal and an LO wave, and offers the same advantages.

Numerous variants may be made in the sixth embodiment mentioned above as follows.

Although it is assumed that the IF signal is an unbalanced signal in the above-mentioned explanation, the sixth embodiment is not limited to the case. Alternatively, the sixth embodiment can also be applied to a case where the IF signal is a balanced signal. Fig. 30 is a schematic circuit diagram showing the structure of an even harmonic mixer for mixing an IF signal which is a balanced signal according to a variant of the sixth embodiment. In this variant, the inverted IF terminal 9b connected to the node between the third and fourth resistors 19a and 19b is removed, the first resistor 10a, the first diode 1a, and the first capacitor 17a are connected in series in the first series unit, and the second resistor 10b, the second diode 1b, and the second capacitor 17b are connected in series in the second series unit. As a

result, the IF signal is input and output as an unbalanced signal only to and from the IF terminal 9. Even in this variant, since the APDP 11 shows a DC characteristic that does not greatly depend on a change in the LO wave electric power and a change in the temperature of each diode of the APDP, like that as shown in Fig. 27, it is possible to reduce the amount of change in the conversion gain resulting from the change in the LO wave electric power and the change in the temperature of each diode of the APDP.

Although the number of diodes included in each series unit which constitutes the APDP 11 is one in the above-mentioned sixth embodiment and variants, the number of diodes is not limited to one and two or more diodes can be cascaded in each series unit of the APDP. This variant makes it possible to further reduce the amount of distortion to be created when the level of an input signal is increased, as mentioned in Embodiment 2.

Embodiment 7.

Fig. 31 is a schematic circuit diagram showing the structure of an even harmonic mixer according to a seventh embodiment of the present invention. In the figure, the same reference numerals as shown in Fig. 10 denote the same components as those of the even harmonic mixer according to the above-mentioned first embodiment or like components, and the explanation of those components will be omitted hereafter. In an APDP 11 according to the seventh embodiment, a first resistor 10a is connected to a cathode of a first diode 1a in a first series unit of the APDP and a second resistor 10b is connected to an anode of a second diode 1b in a second series unit of the APDP so that the first and second resistors 10a and 10b are

connected to each other at an end of the APDP 11.

Furthermore, in Fig. 31, reference numeral 10c denotes a third resistor having an end connected in series to an anode of the first diode 1a, reference numeral 10d denotes a fourth resistor having an end connected in series to a cathode of the second diode 1b, reference numeral 16a denotes a first capacitor connected in parallel to the third resistor 10c, reference numeral 16b denotes a second capacitor connected in parallel to the fourth resistor 10d, reference numeral 18a denotes a third capacitor having an end connected to a node between the cathode of the first diode 1a and the first resistor 10a, and reference numeral 18b denotes a fourth capacitor having an end connected to a node between the anode of the second diode 1b and the second resistor 10b. The first and second resistors 10a and 10b are connected to each other and a node between them is connected to an IF terminal 9a. The other ends of the third and fourth resistors 10c and 10d is connected to each other, and a node between them is connected to an inverted IF terminal 9b by way of a LPF 6 and is also connected to a ground potential by way of a HPF 40. The other ends of the third and fourth capacitors 18a and 18b are connected to each other, and a node between them is connected to an RF terminal 7 by way of the HPF 40 and is also connected to an LO terminal 8 by way of a BPF 5. Each of the first through fourth capacitors 16a, 16b, 18a, and 18b has a capacitance set to a value which allows an RF signal and an LO wave to pass therethrough and blocks an IF signal.

Next, the operation of the even harmonic mixer according to the seventh embodiment will be explained.

The description will be made assuming that the even harmonic mixer is the one intended for reception in which an

RF signal and an LO wave are applied to the RF terminal 7 and the LO terminal 8, respectively, and an IF signal and the inversion of the IF signal are extracted from the IF terminal 9a and the inverted IF terminal 9b, respectively.

The RF signal applied to the RF terminal 7 is input to the APDP 11 by way of the HPF 40. The input RF signal is then furnished to either the first diode 1a or the second diode 1b by way of the third capacitor 18a or the fourth capacitor 18b, and further reaches the ground potential by way of either the first capacitor 16a or the second capacitor 16b and by way of the HPF 40. Therefore, any voltage drop in the RF signal is not caused because of the first through fourth resistors 10a, 10b, 10c, and 10d. On the other hand, since a direct current is blocked by the third and fourth capacitors 18a and 18b, a parallel circuit, which consists of the first series unit in which the first diode 1a and the first and third resistors 10a and 10c are connected to each other and the second series unit in which the second diode 1b and the second and fourth resistors 10b and 10d are connected to each other, operates like the APDP according to the above-mentioned first embodiment. Therefore, even in the even harmonic mixer which employs the APDP 11 constructed as above, since the DC characteristic of the APDP 11 does not greatly depend on a change in the LO wave electric power and a change in the temperature of each diode of the APDP, it is possible to reduce the amount of change in the conversion gain resulting from the change in the LO wave electric power and the change in the temperature of each diode of the APDP.

Furthermore, because the IF signal generated by either the first diode 1a or the second diode 1b is blocked by the first through fourth capacitors 16a, 16b, 18a and 18b, the IF signal

and the inversion of the IF signal are output from a node between the first and second resistors 10a and 10b and a node between the third and fourth resistors 10c and 10d, respectively. At this time, the RF signal is blocked by the first through fourth resistors 10a, 10b, 10c, and 10d and does not appear at the IF terminal 9a and the inverted IF terminal 9b because each of the first through fourth capacitors 16a, 16b, 18a, and 18b has an impedance smaller than the resistance of each of the first through fourth resistors 10a, 10b, 10c, and 10d. Therefore, the even harmonic mixer of the seventh embodiment makes it possible to output the IF signal as a balanced signal even if there is no low-pass filter that allows only IF signals to pass therethrough, though such a low-pass filter is needed in the first through third embodiments mentioned above.

The even harmonic mixer according to the seventh embodiment is available as a mixer for transmission which inputs an IF signal and outputs both an RF signal and an LO wave, and offers the same advantages.

Numerous variants may be made in the seventh embodiment mentioned above as follows.

Although it is assumed that the IF signal is an unbalanced signal in the above-mentioned explanation, the seventh embodiment is not limited to the case. Alternatively, the seventh embodiment can also be applied to a case where the IF signal is a balanced signal. Fig. 32 is a schematic circuit diagram showing the structure of an even harmonic mixer for mixing an IF signal which is a balanced signal according to a variant of the seventh embodiment. In this variant, the inverted IF terminal 9b connected, by way of the LPF 6, to the node between the third and fourth resistors 10c and 10d is removed. As a

result, the IF signal is input and output as an unbalanced signal only to and from the IF terminal 9. Even in this variant, since the APDP 11 shows a DC characteristic that does not greatly depend on a change in the LO wave electric power and a change in the temperature of each diode of the APDP, like that as shown in Fig. 27, it is possible to reduce the amount of change in the conversion gain resulting from the change in the LO wave electric power and the change in the temperature of each diode of the APDP.

Although the number of diodes included in each series unit which constitutes the APDP 11 is one in the above-mentioned seventh embodiment and variants, the number of diodes is not limited to one and two or more diodes can be cascaded in each series unit of the APDP. This variant makes it possible to further reduce the amount of distortion to be created when the level of an input signal is increased, as mentioned in Embodiment 2.

Embodiment 8.

Fig. 33 is a schematic circuit diagram showing the structure of an even harmonic mixer according to an eighth embodiment of the present invention. In the figure, the same reference numerals as shown in Fig. 21 denote the same components as those of the even harmonic mixer according to the above-mentioned third embodiment or like components, and the explanation of those components will be omitted hereafter. In an APDP 11 according to the eighth embodiment, a first resistor 10a is connected to a cathode of a first diode 1a in a first series unit of the APDP and a second resistor 10b is connected to an anode of a second diode 1b in a second series unit of the

APDP so that the first and second resistors 10a and 10b are connected to each other at an end of the APDP 11. A first capacitor 14a is connected in parallel to the first resistor 10a, and a second capacitor 14b is connected in parallel to the second resistor 10b.

Furthermore, in Fig. 33, reference numeral 20a denotes a third capacitor having an end connected in series to an anode of the first diode 1a, reference numeral 20b denotes a fourth capacitor having an end connected in series to a cathode of the second diode 1b, reference numeral 21a denotes a third resistor having an end connected to a node between the anode of the first diode 1a and the third capacitor 20a, and reference numeral 21b denotes a fourth resistor having an end connected to a node between the cathode of the second diode 1b and the fourth capacitor 20b. A node between the first and second resistors 10a and 10b is connected to an RF terminal 7 by way of a HPF 4, an LO terminal 8 by way of a BPF 5, and an IF terminal 9a by way of the LPF 6. The other ends of the third and fourth resistors 21a and 21b is connected to each other, and a node between them is connected to an inverted IF terminal 9b. The other ends of the third and fourth capacitors 20a and 20b are connected to each other, and a node between them is connected to a ground potential. Each of the first through fourth capacitors 14a, 14b, 20a, and 20b has a capacitance set to a value which allows an RF signal and an LO wave to pass therethrough and blocks an IF signal.

Next, the operation of the even harmonic mixer according to the eighth embodiment will be explained.

The description will be made assuming that the even harmonic mixer is the one intended for reception in which an RF signal and an LO wave are applied to the RF terminal 7 and

the LO terminal 8, respectively, and an IF signal and the inversion of the IF signal are extracted from the IF terminal 9a and the inverted IF terminal 9b, respectively.

The RF signal applied to the RF terminal 7 is input to the APDP 11 by way of the HPF 4. The input RF signal is then furnished to either the first diode 1a or the second diode 1b by way of the first capacitor 14a or the second capacitor 14b, and further reaches the ground potential by way of either the third capacitor 20a or the fourth capacitor 20b. Therefore, any voltage drop in the RF signal is not caused because of the first through fourth resistors 10a, 10b, 21a, and 21b. On the other hand, since a direct current is blocked by the third and fourth capacitors 20a and 20b, a parallel circuit, which consists of the first series unit in which the first diode 1a and the first and third resistors 10a and 21a are connected to each other and the second series unit in which the second diode 1b and the second and fourth resistors 10b and 21b are connected to each other, operates like the APDP according to the above-mentioned first embodiment. Therefore, even in the even harmonic mixer which employs the APDP 11 constructed as above, since the DC characteristic of the APDP 11 does not greatly depend on a change in the LO wave electric power and a change in the temperature of each diode of the APDP, it is possible to reduce the amount of change in the conversion gain resulting from the change in the LO wave electric power and the change in the temperature of each diode of the APDP.

Furthermore, because the IF signal generated by either the first diode 1a or the second diode 1b is blocked by the first through fourth capacitors 14a, 14b, 20a and 20b, the IF signal and the inversion of the IF signal are output from a node between

the first and second resistors 10a and 10b and a node between the third and fourth resistors 21a and 21b, respectively. At this time, the RF signal is blocked by the first through fourth resistors 10a, 10b, 21a, and 21b and does not appear at the IF terminal 9a and the inverted IF terminal 9b because each of the first through fourth capacitors 14a, 14b, 20a, and 20b has an impedance smaller than the resistance of each of the first through fourth resistors 10a, 10b, 21a, and 21b. Therefore, the even harmonic mixer of the eighth embodiment makes it possible to output the IF signal as a balanced signal even if there is no low-pass filter that allows only IF signals to pass therethrough, though such a low-pass filter is needed in the first through third embodiments mentioned above.

The even harmonic mixer according to the eighth embodiment is available as a mixer for transmission which inputs an IF signal and outputs both an RF signal and an LO wave, and offers the same advantages.

Numerous variants may be made in the eighth embodiment mentioned above as follows.

Although it is assumed that the IF signal is an unbalanced signal in the above-mentioned explanation, the eighth embodiment is not limited to the case. Alternatively, the eighth embodiment can also be applied to a case where the IF signal is a balanced signal. Fig. 34 is a schematic circuit diagram showing the structure of an even harmonic mixer for mixing an IF signal which is a balanced signal according to a variant of the eighth embodiment. In this variant, the inverted IF terminal 9b connected to the node between the third and fourth resistors 21a and 21b is removed, the first resistor 10a, the first diode 1a, and the third capacitor 20a are connected in series in the

first series unit, and the second resistor 10b, the second diode 1b, and the fourth capacitor 20b are connected in series in the second series unit. As a result, the IF signal is input and output as an unbalanced signal only to and from the IF terminal 9a. Even in this variant, since the DC characteristic of the APDP 11 does not greatly depend on a change in the LO wave electric power and a change in the temperature of each diode of the APDP, it is possible to reduce the amount of change in the conversion gain resulting from the change in the LO wave electric power and the change in the temperature of each diode of the APDP.

Although the number of diodes included in each series unit which constitutes the APDP 11 is one in the above-mentioned eighth embodiment and variants, the number of diodes is not limited to one and two or more diodes can be cascaded in each series unit of the APDP. This variant makes it possible to further reduce the amount of distortion to be created when the level of an input signal is increased, as mentioned in Embodiment 2.

Industrial Applicability

As mentioned above, the even harmonic mixer in accordance with the present invention is suitable for a quadrature modulator and a quadrature demodulator for use in transmitter-receivers of a radio communications system.